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Atty. Dkt. No. CRU/0010

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PATENT

**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

In re Application of:  
Simpson, et al.

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§

Group Art Unit: Unknown

Serial No.: 10/809,275

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§

Filed: March 25, 2004

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Examiner: Unknown

Confirmation No.: Unknown

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§

For: HYDRAULICALLY  
ASSISTED TUBING  
EXPANSION

§  
§

Commissioner for Patents  
Washington, D.C. 20231

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37 CFR 1.8

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26 May 2004  
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**CLAIM TO PRIORITY**

The Applicant reaffirms the claim for the benefit of the filing date of the following foreign patent application referred to in Applicant's Declaration:

Great Britain Application Serial Number 0306774.1 filed March 25, 2003;

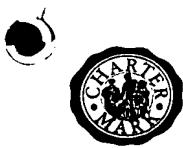
A copy of the application certified by the Great Britain Patent Office is enclosed.

Respectfully submitted,

William B. Patterson

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INVESTOR IN PEOPLE

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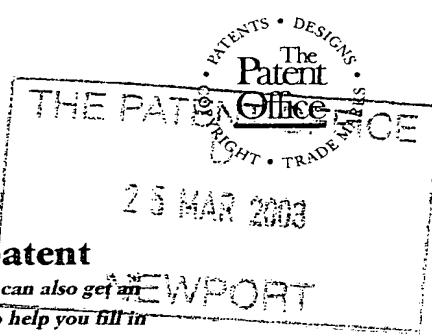
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25MARCH 2003 E794831-1 000259  
201/7700 0.00-0306774.1

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1. Your reference AS / JM / P12737GB

2. Patent application number  
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0306774.1

3. Full name, address and postcode of the or of each applicant (underline all surnames)

WEATHERFORD/LAMB, INC.  
515 POST OAK BOULEVARD  
SUITE 600  
HOUSTON  
TX 77027  
UNITED STATES OF AMERICA

Patents ADP number (if you know it)

8596298001

If the applicant is a corporate body, give the country/state of its incorporation

Declaration as AL B-6-03 - J.D.

4. Title of the invention HYDRAULICALLY ASSISTED TUBING EXPANSION

5. Name of your agent (if you have one)

CRUIKSHANK &amp; FAIRWEATHER

"Address for service" in the United Kingdom to which all correspondence should be sent (including the postcode)

19 ROYAL EXCHANGE SQUARE  
GLASGOW G1 3AE  
UNITED KINGDOM

Patents ADP number (if you know it)

547002

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Country

Priority application number  
(if you know it)Date of filing  
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7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application

Date of filing  
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Statement of inventorship and right to grant of a patent (Patents Form 7/77)

Request for preliminary examination and search (Patents Form 9/77)

1

Request for substantive examination (Patents Form 10/77)

Any other documents  
(please specify)

11. I/We request the grant of a patent on the basis of this application.

Signature

Date

CRUIKSHANK & FAIRWEATHER

24 MARCH 2003

12. Name and daytime telephone number of person to contact in the United Kingdom

ANDREW SHANKS - 0141-221-5767

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## HYDRAULICALLY ASSISTED TUBING EXPANSION

## FIELD OF THE INVENTION

5 This invention relates to hydraulically assisted tubing expansion. In particular, but not exclusively, the invention relates to hydraulically assisted diametric expansion of tubing downhole.

## 10 BACKGROUND OF THE INVENTION

One of the most significant recent developments in the oil and gas exploration and production industry has been the introduction of technology which allows for expansion of extended sections of tubing downhole. The 15 expandable tubing may take different forms, including but not limited to: casing, liner, sandscreen, straddles, packers and hangers. A variety of expansion methods have been proposed, including use of expansion cones or mandrels, which are forced through the tubing.

20 One difficulty that has been experienced with cone expansion is the requirement to apply significant forces to the cone to drive the cone through the tubing. The driving force may be applied mechanically, or hydraulically. Use of hydraulic pressure offers certain 25 advantages, but typically requires the entire tubing to

be pressurised, and also the provision of an effective seal or seals to prevent leakage of high-pressure fluid.

The sole use of fluid pressure to expand tubing, rather than mechanical expansion techniques utilising cones or other devices, is perceived to involve a degree of uncertainty, as it is difficult to predict how a particular tubular will expand in response to an internal fluid pressure which creates a force above the yield strength of the tubular. In particular, a point or area of relative weakness in the tubing wall may result in the tubing bursting or expanding in a non-uniform manner. In addition, and as noted above, use of elevated hydraulic pressure typically requires the entire tubing to be pressurised, and also the provision of an effective seal or seals to prevent leakage of high-pressure fluid.

A number of these difficulties are addressed in applicant's WO 02/081863, the disclosure of which is incorporated herein by reference, in which a tubing expansion process is described utilising a combination of both mechanical and hydraulic expansion forces.

It is among the objectives of embodiments of the present invention to provide a method of expanding tubing, particularly in a downhole environment, which relies at least in part on hydraulic expansion forces.

## SUMMARY OF THE INVENTION

According to the present invention there is provided a method of expanding tubing, the method comprising applying a varying fluid pressure to the tubing.

5        The varying fluid pressure preferably acts across the wall of the tubing. The variation in pressure may be achieved by any appropriate means, and one or both of the fluid pressure within the tubing and the fluid pressure externally of the tubing may be varied. A body of  
10      varying volume may be located in a volume of fluid operatively associated with the tubing. Alternatively, or in addition, the volume of a body of fluid operatively associated with the tubing may be varied by movement of a wall portion defining a boundary of the volume, which  
15      wall portion may be operatively associated with an oscillator or a percussive or hammer device. In other embodiments a pressurised fluid source may be provided, and the fluid may be supplied at varying pressure from the source or the manner in which the fluid is delivered  
20      to the tubing from the source may be such to vary the fluid pressure. An increase in pressure within the tubing may be accompanied by a reduction in pressure externally of the tubing, or a reduction of pressure externally of the tubing may occur independently of any  
25      variations in the internal pressure, which may remain

substantially constant.

References herein to expansion are primarily intended to relate to diametric expansion achieved by extension of the tubing wall which may be achieved by 5 various means, as will be described. However, embodiments of the invention may also relate to tubing which is expanded by reforming a tubing wall, for example by straightening or smoothing a corrugated tubing wall.

In one embodiment, in a downhole application, the 10 fluid pressure externally of the tubing may be maintained at a relatively low level by providing a relatively low density fluid externally of the tubing. Thus, the hydrostatic pressure produced by the column of fluid above the tubing will be relatively low. This may be 15 achieved by injecting gas or low density fluid into fluid surrounding the tubing. Alternatively, or in addition, a volume of fluid externally of the tubing may be at least partially isolated from the head of fluid above the tubing, for example by means of a seal or seals between 20 the tubing and a surrounding bore or tubing wall, or by providing pumping means above the tubing.

Alternatively, or in addition, the fluid pressure internally of the tubing may be maintained at a relatively high level by providing a relatively high 25 density fluid internally of the tubing. This feature may

be utilised in other forms of tubing expansion, not reliant on a varying pressure. In particular, the use of a high density fluid will provide a relatively high hydrostatic pressure, reducing or even eliminating the 5 need to utilise pumps to provide the desired fluid pressure in the bore. The elevated fluid pressure achieved by providing a column of high density fluid may in addition, or alternatively, be utilised for other purposes, such as driving an expansion cone or other tool 10 through the tubing.

The portion of tubing to be expanded may be isolated from ambient fluid by one or more appropriate seals, and a varying pressure differential may be maintained across each seal. However, in accordance with a further aspect 15 of the invention a degree of leakage past the seals may be permissible, and in some cases may even be desirable, particularly if means for providing or creating a cycling fluid pressure is being utilised; if the frequency or rate of pressure variation is sufficiently high, a degree 20 of leakage, and the corresponding pressure decay, will not adversely affect the expansion process and may assist in providing the desired pressure cycling when combined with an appropriate source of pressure. In particular, the method may include the step of producing a pressure 25 pulse, and thus an elevated fluid pressure, which then

reduces or decays, which may be due in part to leakage across the seal, or some other mechanism, for example the movement of a reciprocating piston. Furthermore, the ability to utilise "leaky" seals tends to facilitate use  
5 of the expansion method, as there are difficulties involved in providing a fully effective seal in many environments: when expanding tubing downhole, the tubing will often not be perfectly cylindrical, and the tubing diameter may be variable; the tubing surface is unlikely  
10 to be perfectly smooth, and may include profiles; the ambient fluid in the tubing may contain particulates and contaminants; and in preferred embodiments the seal will move relative to the tubing as the tubing is expanded, which movement would of course result in wear to one or  
15 both of the seal and the tubing, and which movement would have to overcome friction, which could be considerable if a leak-free seal was provided or required. Also, the leakage of fluid through, around or over the seal will provide lubrication, facilitating relative movement  
20 between the seal and the tubing.

The seal may take any appropriate form, but is preferably in the form of a labyrinth seal. Typically, the seal comprises a plurality of seal members, each seal member adapted to maintain a proportion of the total  
25 pressure differential across the seal. The number of

seal members may be selected depending upon a number of considerations, including the form of the seal members, tubing form and condition, ambient conditions, the pressure differential to be maintained, tubing diameter, 5 and the frequency or rate of variation of the fluid pressure. Of course such a seal configuration may also be suitable for use in situations where the fluid pressure is substantially constant, or is maintained above at least a minimum level, provided of course that 10 means is provided for maintaining the expansion pressure at the desired level, despite leakage past the seal. Thus, perhaps five, ten, fifteen or more seal members may be provided, as appropriate. The number of seal members may be selected to provide for redundancy, such that 15 failure or damage of one or more seal members will not adversely affect the expansion process.

The expansion may take place solely, or at least substantially, as a result of fluid pressure applied to the tubing wall. In these circumstances, using a varying 20 fluid pressure diminishes the likelihood of uncontrolled expansion. However, the tubing may be located such that there is only a limited or controlled degree of expansion possible, for example the tubing may be located within a slightly larger bore or tubing, and in such cases, and in 25 accordance with other aspects of the invention, a

continuously elevated pressure may be utilised to achieve expansion. Expansion relying solely or predominately on fluid pressure may not necessarily produce expanded tubing of constant form or diameter, however the tubing 5 may also be expanded or formed by other means, such as a mechanical expansion or reforming device, to achieve a desired consistent form. Of course the degree of mechanical reforming or expansion is likely to be relatively small, and such will not require application 10 of substantial expansion forces, and thus may be carried out relatively easily and economically.

The fluid pressure may be maintained at a base pressure, for example at 70% of the yield pressure of the wall of the tubing, upon which base pressure additional 15 pressure pulses or spikes are superimposed. The pulses or spikes will take the fluid pressure closer to the yield pressure, preferably approaching or close to the yield pressure. In certain embodiments the fluid pressure will be equal to or in excess of 100% of the 20 yield pressure, to induce plastic deformation of the tubing.

Expansion of the tubing may be assisted by the presence of a mechanical expansion or reforming device, such as an expansion cone, mandrel or die, or a rotary 25 expansion device. The mechanical device may exert little

or no expansion force, and may merely serve to stabilise the expansion process and assist in achieving a desired expanded form, for example achieving a desired expanded diameter and avoiding ovality. Alternatively, or in 5 addition, the mechanical expansion or reforming device may serve to retain expansion induced by the elevated fluid pressure. In one embodiment, a shallow angle cone may be advanced through the expanding tubing, the cone preferably being advanced in concert with the periods of 10 elevated pressure. The cone angle may be selected depending upon the particular application, but for downhole tubulars of conventional form it has been found that an 11 degree cone angle results in a cone which retains expansion, that is the cone may be advanced into 15 the tubing expanded by the elevated pressure, and is then retained in the advanced position as the tubing contracts on decay of the fluid pressure below the tubing wall yield pressure. It is anticipated that by cycling the fluid pressure at a rate of around 5 Hertz the cone will 20 advance at a rate of approximately 6 to 8 feet per minute. Of course the rate or frequency of fluid pressure variation may be selected to suit local conditions and equipment. Such advancement may be achieved by providing separate mechanical drive means, 25 such as a downhole tractor to push or pull the apparatus

through the tubing, or simply by application of weight from surface, but may be conveniently achieved by virtue of the pressure differential over a seal coupled to the cone; as the pressure peaks, causing expansion of the 5 tubing, the axial differential pressure acting force across the seal will also peak. Where the cone is located between seals, in particular a leading seal and a trailing seal, the leading seal may be mounted on the cone or otherwise coupled to the cone such that any 10 pressure differential across the seal will tend to urge the cone forward. The trailing seal may be located at some point behind the cone, such that the cone is located within an isolated fluid volume between the seals. The trailing seal may be fixable or securable relative to the 15 tubing or may be floating. The trailing seal may be retained in position mechanically or, alternatively or additionally, by fluid pressure, for example by a column of fluid above the seal, which column may be pressurised by appropriate pumps on surface. The variations in 20 pressure are preferably applied to the isolated fluid volume between the seals, and may be created by a pulse generator located within the isolated volume, or by supplying elevated pressure fluid or pressure pulses from a source externally of the isolated volume. In other 25 embodiments, variations in pressure may also be applied

to one or both of the fluid volumes above and below the isolated volume.

While reference is made above predominately to expansion cones, similar advantages and effects may be 5 achieved using other forms of expansion devices.

Of course the presence of fluid will facilitate movement of any expansion device present relative to the tubing, in particular by serving as a lubricant between the contacting surfaces of the expansion device and the 10 tubing. The fluid may be selected for its lubricating properties. This is particularly the case in embodiments where the fluid surrounding the expansion device is at least partially isolated from the ambient fluid, and as such a smaller volume of fluid selected for its 15 particular properties may be provided. Leakage past isolating seals may be accommodated by providing a larger initial volume, or by supplying further fluid to the volume. Of course the fluid may be selected with properties other than lubrication in mind, for example 20 the fluid may comprise or include a relatively viscous element, for example a grease, to minimise the rate of leakage and pressure decay.

In other embodiments, the fluid may contain material or particles intended to facilitate movement between the 25 expansion device and the tubing, such as large numbers of

small spherical particles, which will act as bearings and provide for a relatively large area rolling contact between the expansion device and the tubing. Such particles may be of any appropriate material, such as 5 titanium carbide. It is believed that the spherical grain structure of titanium carbide facilitates in the reduction of friction between the surfaces. In certain embodiments, such particles may be provided in a fluid suspension, the fluid being selected for its lubricating 10 properties. Of course the use of such particles to facilitate relative movement of contacting surfaces is not limited to use with an expansion device, and may be utilised in any application where it is useful to reduce friction between surfaces.

15 Downhole expansion may be accomplished either top down or bottom up, that is expansion process moves downwardly or upwardly through the tubing.

Where an expansion or reforming device is provided, one or both of the tubing and the device may be vibrated, 20 as discussed in greater detail below. Thus, this embodiment comprises the additional steps of:

vibrating at least one of the tubing and the expansion device; and

25 translating the expansion device relative to the tubing.

The vibration of at least one of the tubing and the expansion device preferably acts to reduce friction between the tubing and the device.

In conventional tubing expansion operations an expansion device which slides relative to the tubing to be expanded, such as a cone or mandrel, will tend to progress through the tubing incrementally in a series of small steps. From a static condition, the load on the cone is increased until the load is sufficient to drive the cone through the tubing. In addition to the forces required to expand the tubing diametrically, it is also necessary to overcome the static friction between the contacting surfaces of the cone and the tubing before the cone will move relative to the tubing. Once static friction has been overcome, frictional resistance to movement typically decreases sharply due to the lower dynamic friction between the contacting surfaces, such that the initial movement of the cone will tend to be relatively rapid. As the cone moves forward rapidly relative to the tubing, the driving force being applied to the cone will tend to fall, the inertia of the cone-driving arrangement being such that the cone-driving arrangement will typically fail to keep pace with the cone. Thus, after the initial rapid movement, the cone will tend to stall as the driving force decreases. The

driving force applied to the cone then increases once more, moving the cone forward again once static friction between the cone and tube is overcome. For brevity, this form of movement will hereinafter be referred to as 5 "stick-slip".

With this aspect of the present invention, the vibration of one or both of the expansion device and the tubing is intended such that there will be little or no static friction experienced between the contacting 10 surfaces, and the conventional stick-slip progression of the expansion device relative to the tubing should be avoided. The driving force necessary to drive the expansion device through the tubing should therefore remain relatively constant, as the frictional forces 15 remain at a relatively constant, and relatively low, level.

Furthermore, the reduction in friction between the expansion device and the tubing should tend to decrease the wear experienced by the expansion device, which in 20 conventional expansion operations may place limits on the length of tubing which can be expanded in a single expansion operation.

The frequency and amplitude of vibration may be selected to suit each particular application. 25 Furthermore, the direction of vibration may be selected

as appropriate: for example, the vibration may be random, multi-directional, axial, transverse or rotational. In one embodiment of the invention the vibration is substantially perpendicular to the surface 5 of the expansion device, and in another embodiment the vibration takes the form of torsional oscillations.

Where the expansion device is vibrated, all or a major portion of the device may be subject to vibration. Alternatively, only a selected portion of the device may 10 be subject to vibration, for example only a surface portion of the device, or only a selected area of the surface of the device, may be subject to vibration. Portions of the expansion device may also experience different degrees or forms of vibration.

15 If the tubing is vibrated, all or a substantial portion of the tubing may be vibrated. Alternatively, only a selected portion of the tubing may be vibrated. For example, only a portion of the tubing at or adjacent 20 the expansion device may be vibrated, or only a surface portion of the tubing may be vibrated.

The vibration of the expansion device or tubing may induce physical movement of the device or tubing. Alternatively, or in addition, the vibration of the device or tubing may induce contraction and expansion of 25 all or a portion of the device or the tubing. For

example, the vibration may take the form of one or more waves traveling through the device or tubing.

The vibration may be induced or created locally relative to the expansion device or the tubing being 5 expanded, or may be created remotely, for example a wave form oscillation may be created remote from the expansion device location, and then travel along or through the tubing wall, or travel to the expansion location via another medium.

10 The vibration may be created by any appropriate means, including: an oscillating or otherwise moving mass; creating a varying or cyclic restriction to fluid flowing through the expansion device or tubing; an electromagnetic oscillator; varying the pressure of 15 fluid operatively associated with the device or tubing; creating pressure pulses in a fluid; or injecting gas or liquid or a mixture of both into fluid operatively associated with the device or tubing.

The source of vibration or oscillation may be 20 directly or indirectly coupled to one or both of the expansion device and the tubing.

The vibration may be of a constant, varying or substantially random nature, that is the amplitude, direction, frequency and form of the vibration may be 25 constant, varying or random.

The vibration or oscillation may be of high frequency, for example ultrasonic. Such vibration may not be apparent as physical movement, as the vibration may be at a molecular or macromolecular level, or at 5 least at a level below that of readily detectable physical movement of the device or tubing. Such vibration may be induced electro magnetically, for example by a varying electromagnetic field, or a varying or alternating current or voltage. Alternatively, or in 10 addition, the vibration or oscillation may be of relatively low frequency, for example in the range of 1 to 100 Hz. If desired, the vibration may comprise a plurality of different components, for example a low frequency component and a high frequency component.

15 The vibration may be selected to coincide with a natural frequency of the expansion device or the tubing, or another element of apparatus. Alternatively, the vibration may be selected to avoid such natural frequency or frequencies.

20 The expansion device may be translated relative to the tubing by any appropriate means. The device may be mounted on a support which allows the device to be pushed, pulled or otherwise driven through the tubing. The support may extend from a downhole location to 25 surface, where a pushing, pulling or torsional force may

be applied. Alternatively, the expansion device may be coupled to a tractor or other driving arrangement located downhole. Alternatively, or in addition, fluid pressure may be utilised to move the device relative to the 5 tubing. Due to the relatively low forces required to move an expansion device through tubing in the various embodiments of the invention, various means for providing motive force are available which would not provide sufficient force in a conventional tubing expansion 10 operation. Thus, for example, where tubing expansion takes place predominantly as a result of applied fluid pressure, a tractor may provide sufficient motive force to translate the expansion apparatus relative to the tubing; in a conventional tubing expansion operation, it 15 is most unlikely that sufficient motive force could be provided by a tractor.

The expansion device may take any appropriate form and may utilise any appropriate expansion mechanism, or a combination of different expansion mechanisms. An 20 expansion cone or mandrel may be utilised with an expansion surface adapted for sliding or rolling contact with the tubing wall. The cone may be adapted for axial movement relative to the tubing, but may also be adapted for rotation. Alternatively, or in addition, a rotary 25 expander may be utilised, that is a device which is

rotated within the tubing with at least one expansion member, typically a roller, moving around the surface of the tubing and creating localised compressive yield in the tubing wall, the resulting reduction in wall 5 thickness leading to an increase in tubing diameter.

The expansion device may define a fixed diameter, or a variable diameter. The device may be compliant, that is the device has a degree of flexibility to permit the device to, for example, negotiate sections of the tubing 10 which cannot be expanded to a desired larger diameter or form. Alternatively, the expansion device may define a fixed diameter and be non-compliant. In certain embodiments, the expansion device may feature both fixed and compliant elements.

15

#### BRIEF DESCRIPTION OF THE DRAWING

These and other aspects of the present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

20 Figure 1 is a schematic illustration of tubing being expanded downhole in accordance with a preferred embodiment of the present invention; and

Figure 2 is a schematic illustration of tubing being expanded downhole in accordance with a further embodiment 25 of the present invention.

## DETAILED DESCRIPTION OF THE DRAWING

Figure 1 of the drawings illustrates a tubing in the form of a bore lining casing 10 located in a drilled bore 12, such as may be utilised to gain access to a 5 subterranean hydrocarbon reservoir. The casing 10 is run into the bore 12 in a smaller diameter first condition, of diameter  $D_1$ , and is subsequently expanded to a larger second diameter  $D_2$ .

Expansion of the casing 10 is achieved using 10 expansion apparatus 14 mounted on the lower end of a string of drill pipe 16, which extends to surface. The expansion apparatus 14 comprises a semi-compliant expansion cone 18, that is a cone of relatively hard material which defines an outer expansion surface 20 and 15 which defines a maximum expansion diameter corresponding to the expanded tubing diameter  $D_2$ . However, the cone 18 is arranged such that the expansion surface may be deflected radially inwardly to a limited extent to accommodate situations where, for example, the casing 10 20 cannot be expanded to the diameter  $D_2$ . A variable volume pulse generator 22 is mounted to the cone 18 and is supplied with power via a control line (not shown) that extends to surface.

The volume of fluid surrounding the cone 18 and the 25 oscillator 22 is isolated from the remaining fluid in the

casing 10 by seals 24, 26, the leading seal 24 being mounted on the leading end or nose of the cone 18, while the trailing seal 26 is mounted to the trailing end of the oscillator 22. Each seal 24, 26 comprises a plurality of seal members 24a, 24b, 24c, 26a, 26b, 26c as will be described, and in use the seal members 24a-c, 26a-c permit a degree of leakage thereacross. In this example, each seal member is in the form of a split ring, of a somewhat similar form to a piston ring. Thus, a small volume of fluid may pass between the ends of each seal member. However, the number of seal members provided is such that only minimal leakage occurs past each seal 24, 26. Of course other embodiments of the invention may comprise different forms of seal member, for example porous members or members which are intended to allow a degree of leakage between the seal member surface and the tubing surface.

In use, the volume of fluid  $V_1$  in the casing 10 above the seals 26 is at pressure  $P_1$ . The volume  $V_1$  is filled with a relatively high density fluid, resulting in a relatively high hydrostatic pressure above the seals 26. In addition, pumps may be utilised to further increase the pressure above the seals 26.

The volume of fluid  $V_3$  beneath the leading seal 24 is isolated from the high density fluid and is at a

significantly lower pressure  $P_3$  than  $P_1$ .

The volume of fluid  $V_2$  between the seals 24, 26 is maintained at an elevated base pressure  $P_2$ , which pressure is achieved by means of pumps, which will typically be located on surface, and which communicate with the volume  $V_2$  via the drill pipe string 16 and a one-way valve provided in the string 16. The base pressure  $P_2$  may be the same as or more than the pressure  $P_1$  above the seal 26.

10 Each individual seal member 24a, 24b, 24c, 26a, 26b, 26c will only maintain a pressure differential which is less than the pressure differential between volumes  $V_1$  and  $V_2$  or  $V_2$  and  $V_3$ . However, collectively the seal members 24a-c, 26a-c are effective to maintain the rate 15 of leakage or pressure decay at a relatively low level.

The pressure  $P_2$  is selected such that the differential pressure across the wall of the casing 10 is below the yield pressure of the casing 10, for example the pressure  $P_2$  may be 70% of the yield pressure. 20 However, operation of the pulse generator 22 creates pressure pulses that exceed the yield pressure of the casing 10, such that the casing 10 will tend to expand when exposed to the pressure pulses.

The weight of the string 16 and the expansion 25 apparatus 14, and the fluid pressure forces acting on the

apparatus 14, and thus on the cone 18, also results in a mechanical expansion force being applied to the casing 10 by the cone 18, such that the cone 18 will tend to advance and expand a short length of the casing 10 with 5 each pressure pulse. In particular, the pulsing pressure  $P_2$  creates a corresponding differential pressure pulse across the seal 24, and thus creates a pulsing axial force tending to advance the cone 18. Of course this pulsing force will coincide with the maximum pressure, 10 above the casing yield pressure, within the volume  $V_2$ , when the force required to advance the cone 18, and thus mechanically expand the casing 10, will be at a minimum.

If desired, the pressure  $P_1$  above the expansion apparatus 14 may also be pulsed, to apply an additional 15 motive force to the apparatus 14, and to counteract any differential pressure experienced across the seal 26 which might tend to urge the apparatus in the opposite direction.

The cone angle is selected such that the forces 20 acting between the cone surface and the casing 10 will retain the forward travel of the cone 18 following a pressure pulse. In this manner, the casing 10 may be extended in a series of small steps. However, expansion 25 may still take place relatively rapidly. For example, with the pressure between the seals pulsing at 5 hertz,

the cone will progress at a rate of approximately six to eight feet per minute.

The presence of fluid around the cone 18 minimises friction between the contacting surfaces of the cone 18 and casing 10, and furthermore the small degree of leakage across the seal members also serves to provide lubrication for movement of the seals 24, 26 through the casing 10.

In addition to the pressure pulses which may be present in the pressure  $P_1$  and  $P_2$  as noted above, a further pressure variation may be applied to the casing 10 or apparatus 14 with a view to inducing vibration in one or both of the casing 10 or apparatus 14. Such vibration may be utilised to reduce the friction between the apparatus 14 and the tubing 10. This vibration may be the result of further applied fluid pressure pulses, typically of relatively high frequency. Alternatively, the rate of variation of pressure  $P_2$  may be selected to provide both expansion and friction-reducing vibration. These features of the invention are more fully described in our application entitled "Tubing Expansion", being filed concurrently herewith.

Reference is now made to Figure 2 of the drawings, which illustrates expansion apparatus 114 in accordance with a further embodiment of the present invention. The

apparatus 114 shares many features with the apparatus 14 described above, and operates in a broadly similar manner.

In addition to the leading and trailing seals 124, 5 126, swab cups 50 are provided ahead of the leading seal 124, which swab cups 50, in addition to a sealing function, serve to condition the inner surface of the casing 110 ahead of the seal 124, and also assist in stabilising the expansion cone 118.

10 The oscillator 122 is in the form of reciprocating piston pump, a rotary drive 52 being converted to axial movement of the pump piston 54 by an appropriate transfer arrangement 56, such as those described in WO 02\14028, US 5,042,385, US 5,513,709, the disclosures of which are 15 incorporated herein by reference.

Upward movement of the piston 54 draws fluid from the volume beyond the swab cup 50 into the piston cylinder 58 via a conduit 60 incorporating a one-way valve 62. Downward movement of the piston 54 pumps the 20 fluid from the cylinder 58 through a further one-way valve 64 and then through a plurality of conduits 66 to fluid outlets 68 provided in the cone surface 120.

In use, the fluid pressure above the seal 124, that is the pressure between the seals 124, 126 and also above 25 the trailing seal 126, is maintained at a base pressure

corresponding to approximately 70% of the yield pressure of the casing 110, in this example this being around 3000 psi (the yield pressure of the casing 110 is 3700 psi). The oscillator 122 is then operated to pump fluid into 5 the volume V02 between the seals 124, 126 to create short duration 4000 psi pressure pulses within the volume V02, during which the fluid pressure in the small volume around the cone 118 exceeds the casing yield pressure. With each pressure pulse the casing 110 expands by a 10 small degree, in this example, the expansion resulting in 10 a 10 cc increase the volume V02.

A substantially constant weight or force is being applied to the cone 118, for example by provision of a downhole tractor coupled to the string, while the 15 pressure in the volume V02 is pulsed, and at each pulse the cone 118 will advance a short distance to occupy the newly expanded casing 118. The main proportion of the expansion is a result of plastic deformation of the casing 110, while a smaller degree of deformation is 20 elastic, such that the casing 110 will tend to contract to some extent with the decay of the pressure within the volume V02 from the peak pressure produced at each pulse. However, the cone angle is relatively shallow (the cone angle is shown somewhat exaggerated in the Figure) such 25 that the cone 118 will tend to retain any elastic

deformation. Thus, following completion of an expansion operation, it may be necessary to apply a tension to the cone 118 while the pressure in the volume V02 is being pulsed in order to remove the cone 118, if this is 5 desired or necessary: in some cases the cone 118 may be left in the casing 110.

As will be apparent to those of skill in the art, the operation of the oscillator 122 combined with the application of weight to the cone 118 will result in 10 relatively rapid expansion of the casing 110.

Those of skill in the art will recognise that the above described embodiments are merely examples of the present invention, and that various modifications and improvements may be made thereto, without departing from 15 the scope of the invention.

## CLAIMS

1. A method of expanding tubing, the method comprising applying a varying fluid pressure to the tubing.

5

2. The method of claim 1, wherein the tubing is expanded downhole.

3. The method of claim 1 or 2, wherein the varying 10 fluid pressure acts across a wall of the tubing.

4. The method of claim 1, 2 or 3, wherein the pressure within the tubing is varied.

15 5. The method of claim 1, 2, 3 or 4, wherein the pressure externally of the tubing is varied.

6. The method of any of the preceding claims, comprising pumping fluid into a volume of fluid 20 operatively associated with the tubing.

7. The method of any of the preceding claims, comprising locating a body of varying volume in a volume of fluid operatively associated with the tubing.

8. The method of any of the preceding claims, comprising moving a wall portion defining a boundary of a volume of fluid operatively associated with the tubing.

5 9. The method of any of the preceding claims, comprising providing a pressurised fluid source.

10. The method of claim 9, wherein fluid is supplied at varying pressure from the source.

10

11. The method of claim 10, wherein fluid is delivered to the tubing from the source in a manner so as to vary the fluid pressure.

15

12. The method of any of the preceding claims, wherein an increase in pressure within the tubing is accompanied by a reduction in pressure externally of the tubing.

20 13. The method of any of the preceding claims, wherein fluid pressure externally of the tubing is maintained at a relatively low level by providing a relatively low density fluid externally of the tubing.

25 14. The method of claim 13, comprising by injecting a low density fluid into fluid surrounding the tubing.

15. The method of any of the preceding claims wherein a volume of fluid externally of the tubing is at least partially isolated from a head of fluid above the tubing.

5 16. The method of any of the preceding claims, wherein fluid pressure internally of the tubing is maintained at a relatively high level by providing a relatively high density fluid internally of the tubing.

10 17. The method of any of the preceding claims, wherein a cycling fluid pressure is applied to the tubing.

18. The method of any of the preceding claims, wherein a portion of tubing to be expanded is at least partially 15 isolated from ambient fluid by at least one seal, and a varying pressure differential is maintained across the at least one seal.

19. The method of claim 18, wherein a degree of leakage 20 occurs across the at least one seal.

20. The method of claim 19, wherein leaking fluid lubricates the seal.

21. The method of claim 20, comprising producing a pressure pulse, and an associated elevated fluid pressure, which then decays as leakage occurs across the seal.

5

22. The method of any of claims 18 to 21, wherein the seal is moved relative to the tubing as the tubing is expanded.

10 23. The method of any of the proceeding claims, wherein tubing expansion takes place substantially as a result of differential fluid pressure applied across the tubing wall.

15 24. The method of any of the preceding claims, wherein tubing expansion takes place solely as a result of differential fluid pressure applied across the tubing wall.

20 25. The method of any of the preceding claims, wherein the tubing is constrained such that only a limited degree of expansion is achievable.

26. The method of claim 25, wherein the tubing is 25 located within a slightly larger bore.

27. The method of any of the preceding claims, wherein the tubing is mechanically formed.

28. The method of any of the preceding claims, wherein 5 fluid pressure within the tubing is maintained at a base pressure, upon which base pressure a pressure increase is superimposed.

29. The method of claim 28, wherein pressure pulses are 10 superimposed on the base pressure.

30. The method of claim 29, wherein the pressure increase takes the pressure acting on the tubing wall to within 10% of the yield pressure of the tubing wall.

15

31. The method of claim 29, wherein the pressure increase takes the pressure acting on the tubing wall to within 5% of the yield pressure of the tubing wall.

20 32. The method of claim 28 or 29, wherein the pressure increase takes the pressure acting on the tubing wall to at least the yield pressure of the tubing wall.

25 33. The method of any of the preceding claims, wherein a mechanical device is advanced through the tubing to

occupy an increased volume within the tubing created at least in part by the varying fluid pressure.

34. The method of claim 33, wherein the device is  
5 advanced in stepwise fashion in concert with a series of variations in fluid pressure.

35. The method of any of the preceding claims, wherein a mechanical expansion force is applied to the tubing wall.

10

36. The method of any of the preceding claims, wherein a mechanical device retains expansion induced at least in part by fluid pressure.

15 37. The method of claim 36, wherein during periods of lower pressure the mechanical expansion device retains expansion produced during periods of elevated fluid pressure.

20 38. The method of claim 36 or 37, wherein a shallow angle cone is advanced through the tubing to retain expansion.

25 39. The method of any of the preceding claims, wherein a mechanical expansion device is translated relative to the

tubing by fluid pressure.

40. The method of any of the preceding claims, wherein a mechanical expansion device is located between a pair of 5 seals.

41. The method of any of the preceding claims, wherein a leading seal is provided on a mechanical device and the device is translated relative to the tubing by a pressure 10 differential across the seal.

42. The method of any of the preceding claims, wherein the varying pressure is applied to a substantially isolated volume of fluid located between a pair of seals.

15

43. The method of any preceding claim, wherein a mechanical expansion supporting device is provided within a substantially isolated volume located between a pair of seals.

20

44. The method of claim 42 or 43, wherein the varying pressure is created by at least one of: a pulse generator operatively associated with the isolated volume; and by supplying at least one of elevated 25 pressure fluid and pressure pulses from a source

externally of the isolated volume.

45. The method of any of the preceding claims, wherein  
fluid operatively associated with the tubing is selected  
5 for its lubricating properties.

46. The method of any of the preceding claims, wherein  
fluid operatively associated with the tubing is selected  
for its flow characteristics.

10

47. The method of any of the preceding claims, wherein a  
multitude of bearing particles are provided in fluid  
operatively associated within the tubing.

15 48. The method of any of the preceding claims, further  
comprising providing a mechanical device for engaging the  
tubing and supplying fluid to contacting surfaces of the  
device and the tubing.

20 49. The method of any of the preceding claims, further  
comprising providing an expansion device and vibrating at  
least one of the tubing and the device.

25 50. The method of any of the preceding claims, further  
comprising providing expansion apparatus and applying a

motive force to the apparatus to translate the apparatus relative to the tubing.

51. The method of claim 50, wherein the apparatus is  
5 translated by being pulled through the tubing.

52. The method of claim 50 or 51, wherein the apparatus is translated by being pushed through the tubing.

10 53. The method of claim 50, 51 or 52, wherein the motive force comprises a fluid pressure force.

54. The method of any of claims 50 to 53, wherein the motive force comprised a mechanical force.

15

55. The method of claim 54, wherein the motive force is provided by a downhole tractor.

20 56. Apparatus for expanding tubing downhole, the apparatus comprising pressurising means for applying a varying fluid pressure to the tubing.

25 57. The apparatus of claim 56, wherein pressurising means is adapted to create a fluid pressure differential across a wall of the tubing.

58. The apparatus of claim 56 or 57, wherein the pressurising means is adapted to vary the pressure within the tubing.

5 59. The apparatus of any of claims 56 to 58, wherein the pressurising means is adapted to vary the pressure externally of the tubing.

10 60. The apparatus of any of claims 56 to 59, wherein the pressurising means comprises a body of varying volume for location in a volume of fluid operatively associated with the tubing.

15 61. The apparatus of any of claims 56 to 60, wherein the pressurising means includes a movable wall forming a boundary of a volume of fluid operatively associated with the tubing.

20 62. The apparatus of claim 61, wherein the movable wall is operatively associated with an oscillating device.

63. The apparatus of any of claims 56 to 62, wherein the pressurising means comprises a pressurised fluid source.

64. The apparatus of claim 63, wherein the pressurised fluid source is adapted to supply fluid at varying pressure.

5 65. The apparatus of claim 64, comprising means for delivering fluid to the tubing from said source, said delivering means being adapted to vary the pressure of fluid delivered from said source.

10 66. The apparatus of any of claims 56 or 65, wherein the pressurising means comprises means for increasing the pressure within the tubing while reducing the pressure externally of the tubing.

15 67. The apparatus of any of claims 56 to 66, comprising means for reducing the fluid pressure externally of the tubing.

68. The apparatus of claim 67, wherein said means for reducing the fluid pressure externally of the tubing comprises means for injecting gas into the fluid surrounding the tubing.

20 69. The apparatus of any of claims 56 to 68, comprising a reciprocating pump operatively associated with at least

one one-way valve.

70. The apparatus of any of claims 56 to 69, further comprising means for isolating a portion of tubing to be  
5 expanded from ambient fluid.

71. The apparatus of claim 70, wherein said isolating means comprises at least one seal.

10 72. The apparatus of claim 71, wherein said isolating means comprises at least two spaced seals for containing a volume of fluid therebetween.

73. The apparatus of claim 71 or 72, wherein said seal  
15 is adapted to permit a degree of leakage thereacross.

74. The apparatus of any of claims 71 to 73, wherein the seal comprises a plurality of seal members, each seal member adapted to maintain a fluid pressure differential  
20 thereacross.

75. The apparatus of claim 74, wherein the seal comprises at least five seal members.

76. The apparatus of claim 74 or 75, wherein the number of seal members is selected to provide for redundancy.

77. The apparatus of claim 74, 75 or 76, wherein the  
5 seal comprises a labyrinth seal.

78. The apparatus of any of claims 56 to 77, wherein  
said pressurising means comprises means creating a  
cycling fluid pressure.

10

79. The apparatus of any of claims 56 to 78, wherein the  
pressurising means is adapted to produce at least one  
pressure pulse.

15 80. The apparatus of any of claims 56 to 79 further  
comprising a mechanical expansion device.

81. The apparatus of any of claims 56 to 80 where the  
pressurising means is adapted to maintain fluid pressure  
20 within the tubing at a base pressure below the yield  
pressure of the wall of the tubing and superimpose  
pressure pulses thereupon, taking the fluid pressure to  
at least the yield pressure of the wall of the tubing, to  
induce plastic deformation of the tubing.

25

82. The apparatus of any of claims 56 to 81, wherein the pressurising means is adapted to maintain fluid pressure within the tubing at a base pressure below the yield pressure of the wall of the tubing and superimpose 5 pressure pulses thereupon, such that the fluid pressure is then in excess of the yield pressure of the wall of the tubing, to induce plastic deformation of the tubing.

83. The apparatus of any of claims 56 to 82, further 10 comprising a mechanical expansion device.

84. The apparatus of claim 83, wherein the mechanical expansion device comprises an expansion cone.

15 85. The apparatus of claim 83 or 84, wherein the mechanical expansion device comprises a rotary expansion device.

86. The apparatus of any of claims 83, 84 or 85, wherein 20 the expansion device is adapted to stabilise the expansion process.

87. The apparatus of any of claims 83, 84, 85 or 86, wherein the expansion device is adapted to assist in 25 achieving a desired expanded form.

88. The apparatus of any of claims 83 to 87, wherein the mechanical expansion device is adapted to retain expansion induced by elevated fluid pressure.

5 89. The apparatus of any of claims 83 to 88, wherein the expansion device comprises a shallow angle cone.

90. The apparatus of claim 89, wherein the cone angle is 11 degrees or less.

10

91. The apparatus of any of claims 83 to 90, wherein the expansion device is adapted to be advanced through the expanding tubing in concert with periods of elevated pressure.

15

92. The apparatus of any of claims 83 to 91, further comprising drive means for translating the expansion device through the tubing.

20 93. The apparatus of any of claims 83 to 92, further comprising means for translating the expansion device relative to the tubing.

25 94. The apparatus of claim 93, wherein the translating means is a tractor.

95. The apparatus of any of claims 83 to 94, wherein the expansion device is provided in combination with at least one seal adapted to contain a pressure differential thereacross and induce a translating force.

5

96. The apparatus of any of claims 83 to 95, wherein the expansion device is located between a pair of seals.

97. The apparatus of claim 96, wherein the expansion device is located between a leading seal and a trailing seal, the leading seal being mounted coupled to the expansion device such that a pressure differential across the seal will tend to urge the expansion device forward.

15 98. The apparatus of claim 96 or 97, wherein the pressurising means is provided between the seals.

99. The apparatus of claim 98, wherein the pressurising means is in the form of a pulse generator.

20

100. The apparatus of claim 96 or 97, wherein the pressurising means is adapted to supply elevated pressure fluid from a source externally of a volume between the seals.

25

101. The apparatus of any of claims 56 to 100, further comprising means for supplying fluid.

102. The apparatus of any of claims 56 to 101, in  
5 combination with a fluid to be pressurised.

103. The apparatus of claim 102, wherein the fluid comprises a lubricant.

10 104. The apparatus of claim 102 or 103, wherein the fluid has a viscosity selected to minimise leakage past seals associated with the apparatus.

105. The apparatus of any of claims 56 to 104, comprising  
15 an expansion device and means for vibrating one or both of the expansion device and the tubing.

106. A method of expanding tubing by extending a wall of the tubing, the method comprising:

20 applying a base pressure to the tubing, the base pressure being below the yield pressure of the tubing wall; and

applying pressure pulses to the tubing in excess of said base pressure.

107. The method of claim 106 wherein the pressure pulses are such that the tubing wall experiences fluid pressure of at least 90% of the yield pressure of the tubing.

5 108. The method of claim 107 wherein the pressure pulses are such that the tubing wall experiences fluid pressure at least equal to the yield pressure of the tubing.

109. The method of claim 108, comprising applying pressure pulses to the tubing in excess of said base pressure such the tubing wall experiences fluid pressure in excess of the yield pressure of the tubing.

110. A method of expanding tubing by extending a wall of the tubing, the method comprising:

applying a base pressure to the tubing, the base pressure being below the yield pressure of the tubing wall; and

20 applying pressure pulses to the tubing in excess of said base pressure such that the tubing wall experiences an expansion force at least equal to the yield pressure of the tubing.

111. The method of claim 110, wherein said expansion force is provided by at least one of fluid pressure force

and mechanical force.

112. A method of expanding tubing by extending a wall of the tubing, the method comprising:

- 5 isolating a portion of tubing;
- applying a base pressure to the isolated portion of tubing, the base pressure creating a differential pressure across a wall of the tubing below the yield pressure of the tubing wall; and
- 10 applying pressure pulses to the isolated portion of tubing in excess of said base pressure.

113. The method of claim 112, comprising applying pressure pulses to the tubing in excess of said base 15 pressure such that the tubing wall experiences fluid pressure of at least 90% of the yield pressure.

114. The method of claim 113, comprising applying pressure pulses to the tubing in excess of said base 20 pressure such that the tubing wall experiences an expansion force at least equal to the yield pressure of the tubing.

115. A method of expanding tubing by extending a wall of 25 the tubing, the method comprising:

isolating a portion of tubing containing an expansion device;

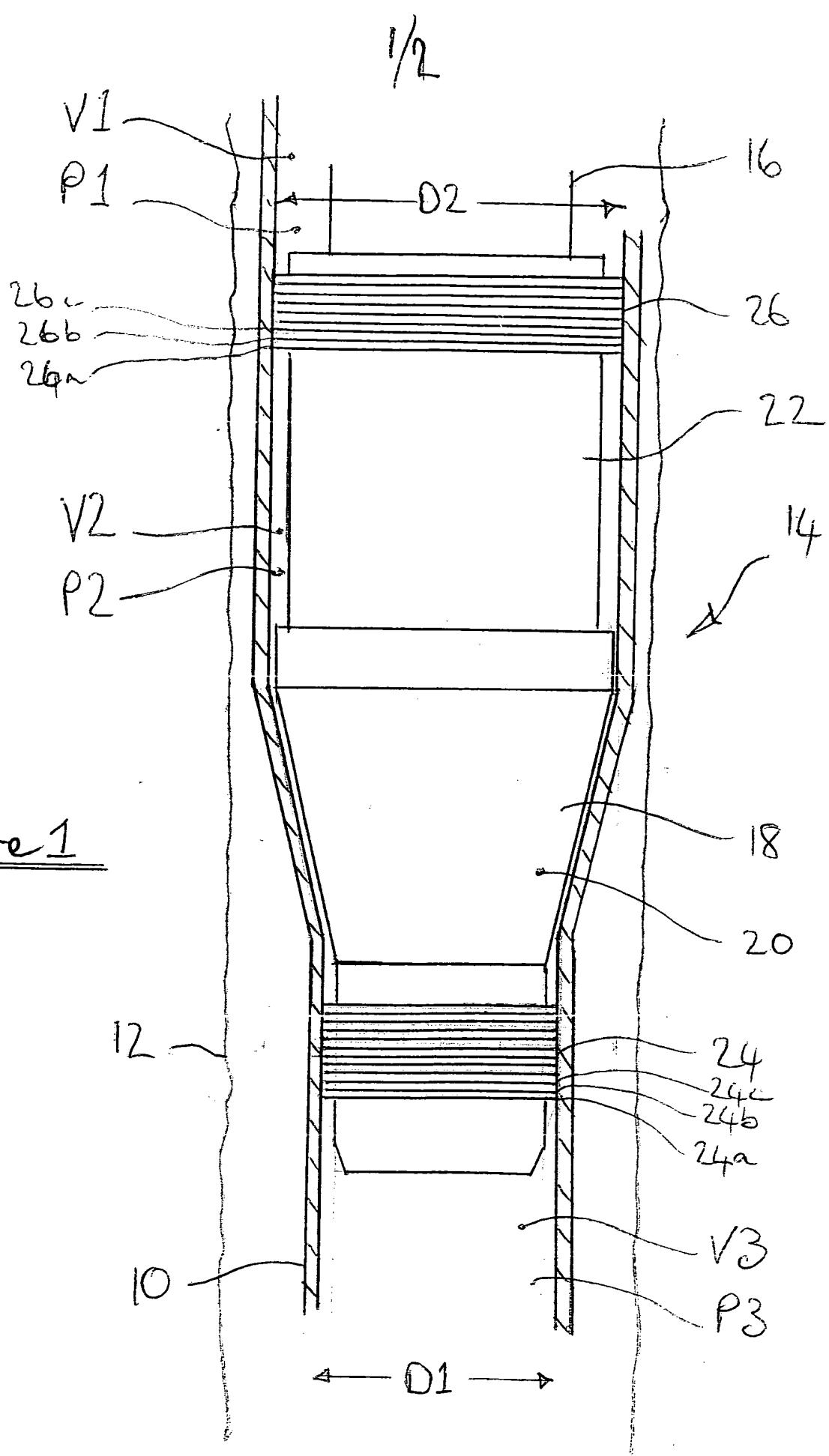
applying a base pressure to the isolated portion of tubing, the base pressure creating a differential 5 pressure across a wall of the tubing below the yield pressure of the tubing wall;

applying pressure pulses to the isolated portion of tubing in excess of said base pressure such that the tubing is expanded; and

10 translating the expansion device to occupy the expanded tubing.

116. A method of expanding tubing downhole, the method comprising providing a column of relatively high density 15 fluid to create a hydrostatic pressure and applying at least said hydrostatic pressure to bear on a selected portion of the tubing.

117. A method of creating a fluid pressure actuating 20 force in a bore, the method comprising providing a column of relatively high density fluid to create hydrostatic pressure and utilising said hydrostatic pressure to create an actuating force.



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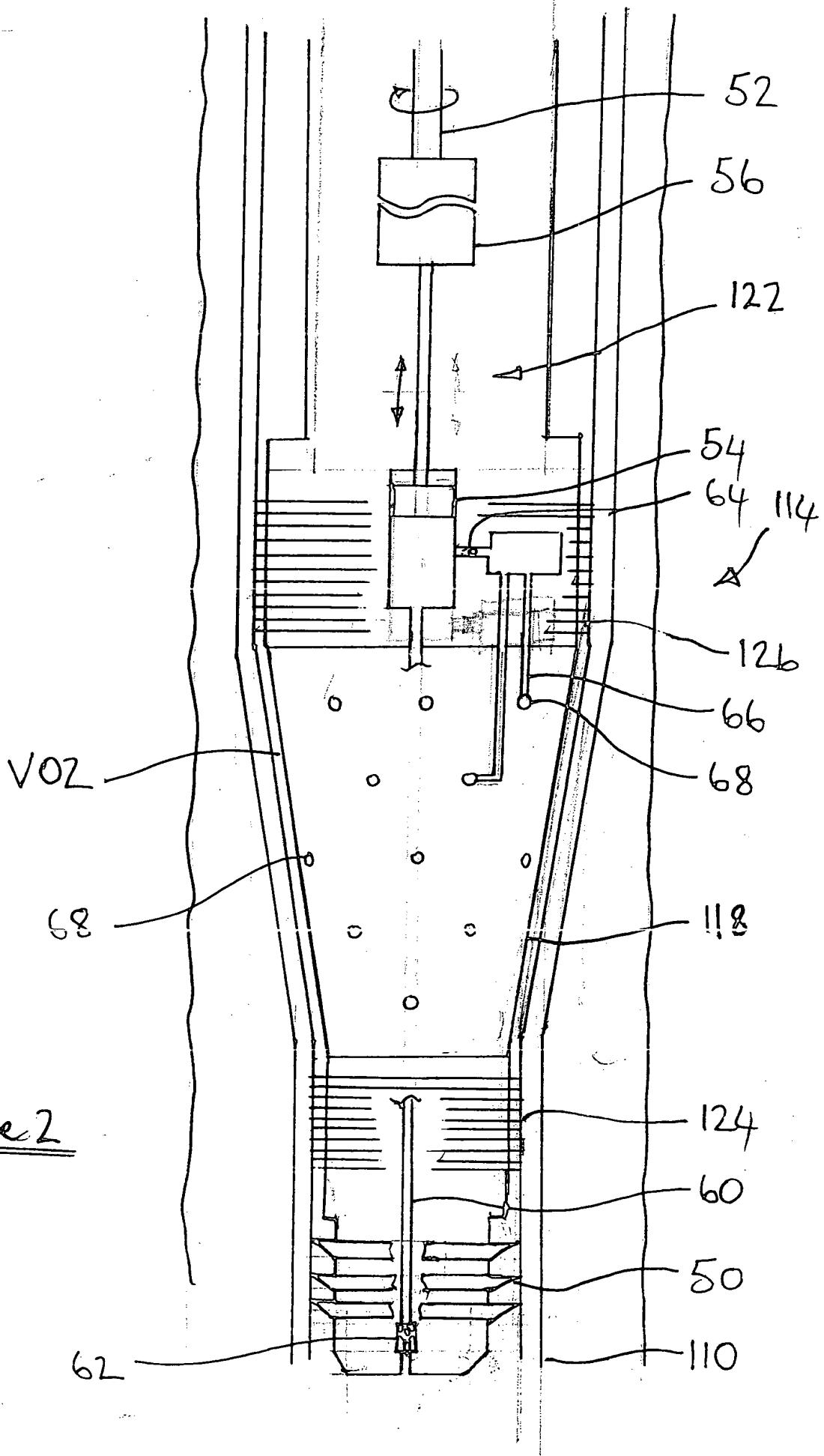


Figure 2

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